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optic cable during the process of assembling the individual optical fibers into a fiber optic cable. Thus, even when starting with individual optical fibers having acceptable light transmission times, the resulting fiber optic cable can have excessive skew, i.e., can have optical fibers which exhibit too great a difference in their respective light transmission times. Another drawback is the manufacturing inefficiency resulting from having to select each individual optical fiber for use in a single fiber optic cable prior to assembling the fiber optic cable.

[0007] What is needed, but is not provided by the conventional art, is a method of testing and adjusting the skew of a fiber optic cable, or a group of optical fibers, that allows greater manufacturing efficiency when producing fiber optic cables.

[0008] SUMMARY

[0009] Briefly stated, one embodiment of the present invention is directed to a method of testing optical fibers. The method includes: providing at least two optical fibers; transmitting a light at a first end of the at least two optical fibers; measuring a light transmission time for each of the at least two optical fibers; determining a difference in the light transmission times for the at least two optical fibers; determining whether the difference in light transmission times is above a predetermined value; and if the difference in the light transmission times is above the predetermined value, adjusting an amount of optical material forming at least one of the at least two optical fibers to reduce the difference in the light transmission times.

[0010] Another embodiment of the present invention is directed to a method of testing a fiber optic cable. The method includes: providing a fiber optic cable having a first and second end, the fiber optic cable including at least two optical fibers; transmitting light at the first end of the fiber optic cable; measuring the light transmission time for the light to

travel through each of the at least two optical fibers of the fiber optic cable; determining the difference in the light transmission times for the at least two optical fibers of the fiber optic cable; and determining whether the difference in the light transmission times is above a predetermined value.

[0011] BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The foregoing summary, as well as the following detailed description of the preferred embodiments of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there are shown in the drawings embodiments which are presently preferred. It is understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown. In the drawings:

[0013] Fig. 1 is a schematic diagram of a system for testing at least two optical fibers according to the preferred embodiment of the present invention;

[0014] Fig. 2 is a side elevational view of an optical fiber segment being attached to one of the optical fibers of Fig. 1;

[0015] Fig. 3 is a side elevational view of one of the optical fibers of Fig. 1 illustrating a length of the optical fiber segment to be removed from the optical fiber;

[0016] Fig. 4 is a flow chart of a method of testing at least two optical fibers according to the present invention;

[0017] Fig. 5 is a flow chart of a method of testing a fiber optic cable according to the present invention.

[0018] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] Referring to Figs. 1-5 in detail, wherein like numerals designate like elements throughout, there is shown a system for testing optical fibers or a fiber cable, generally designated 1. Generally speaking, the present invention is directed to detecting skew and, if appropriate, eliminating at least some of the difference in the light transmission times of the optical fibers 10 that will be used in a single fiber optic cable or application. By reducing the difference in light transmission times, errors in the processing of digital information by highspeed computer processors can be reduced or eliminated.

[0020] Fig. 1 illustrates a preferred system for testing optical fibers 10 or fiber optic cables 28. It is preferred that a light signal generator 12 be optically connected to a first end 22 of the first optical fiber 10 being tested and that an optical detector 14 be optically connected to a second end 24 the optical fiber 10. After the light transmission time through the optical fiber 10 being tested is measured, the light signal generator 12 and optical detector 14 are switched to the next optical fiber 10. If desired, multiple light signal generators 12 and optical detectors 14 can be attached to the optical fibers 10 to allow simultaneous measurement of light transmission times. The preferred light signal generator for use with the present invention is any optical pulse generator capable of providing a rise time of less than twenty (20) picoseconds. The preferred optical detector for use with the present invention is a high speed photo receiver having a rise time compatible with that of the pulse optical generator. The light signal generator 12 and the optical detector 14 are preferably controlled and operated by a control system 16. It is preferred that the control system 16 be a digital sampling oscilloscope having a bandwidth greater than twenty (20) gigahertz and a rise time of less than twenty (20) picoseconds. Those of ordinary skill in the art will appreciate from this disclosure that other suitable light signal generators 12, optical

detectors 14, and control systems 16 can be used without departing from the scope of the present invention.

[0021] A method of testing at least two optical fibers 10 according to the present invention includes providing at least two optical fibers 10. The optical fibers 10 are preferably formed by thin, flexible filaments having a diameter of 10-60 microns. The interior (not shown) of the optical fiber 10 preferably consists of a high refractive index optical glass and is surrounded by a sheath (not shown) of glass having a lower refractive index. The optical fibers 10 in the present invention can be produced using a drawing process or by any other known process for forming optical fibers 10.

[0022] Referring to Fig. 4, a method of testing optical fibers 10 according to the present invention includes the step of transmitting light at the first end 22 of the at least two optical fibers 10. It is preferable, that the step of transmitting light includes transmitting light having a predetermined wavelength. It is also preferable that the step of transmitting light include optically connecting the light signal generator 12 to the first end 22 of the at least two optical fibers 10.

[0023] The testing of optical fibers according to the present invention includes the step of measuring a light transmission time for each of the at least two optical fibers 10. The light transmission time for each optical fiber 10 is the amount of time necessary for a light signal to travel the length of the respective optical fiber 10. Accurate measurement of light transmission times is preferably performed by the control system 16 which activates and monitors the light signal generator 12 and the optical detector 14. It is preferred that the method of testing optical fibers 10 include optically connecting the optical detector 14 to the second end 24 of the at least two optical fibers 10. Alternatively, the measuring of light transmission times can be performed by connecting a second end 24 of each of the optical fibers 10 to an optical detector 14 without departing from the scope of the present invention.

[0024] The testing of optical fibers 10 according to the present invention includes determining a difference in the light transmission times for the optical fibers 10. The difference in light transmission times is obtained by subtracting the shortest light transmission time from the longest light transmission time for the at least two optical fibers 10.

[0025] The testing of optical fibers 10 according to the present invention also includes determining whether the difference in light transmission times is above a predetermined value. The particular predetermined value for a specific optical fiber 10 depends on the application for which the optical fiber 10 will be used. For example, when optical fibers 10 are to be used with computer systems having relatively slow processor speeds, a greater difference in light transmission times can be tolerated without generating errors in the received data. However, when optical fibers 10 are used in computer systems having relatively fast processor speeds, reducing differences in light transmission times is beneficial in reducing digital processing errors. The methods of the present invention provide more efficient and economical methods of producing fiber optic cables 28, or groups of optical fibers 10, having a reduced amount of skew (i.e., a smaller difference in the light transmission times for the relevant optical fibers 10).

[0026] If the difference in light transmission times is above the predetermined value, the testing of optical fibers 10 according to the present invention includes the step of adjusting an amount of optical material forming at least one of the optical fibers 10 to reduce the difference in the light transmission times. The difference in light transmission times can be reduced by increasing the amount of optical material present in the optical fiber(s) 10 having the fastest light transmission time. This results in the light transmission speed of optical fibers 10 used in a common application being reduced closer to that of the slowest light transmitting optical fiber 10. Alternatively, the difference in transmission times can

be reduced by removing optical material from the optical fiber 10 having the longest transmission time. To remove fiber optic material, an optical fiber segment 20 of a predetermined length is removed from the optical fiber 10 being adjusted. This results in the shortened optical fiber(s) having a faster light transmission time and causes the light transmission speed of the optical fibers 10 used in a common application to be increased closer to that of the optical fiber 10 having the fastest light transmission time.

[0027] Referring to Fig. 2, it is preferable that the testing of optical fibers 10 according to the present invention include the step of determining a length of an optical fiber segment 18 to be added to one of the at least two optical fibers 10 having a relatively shorter light transmission time as compared to the optical fiber 10 having the longest light transmission time. The step of determining the length of the optical fiber segment 18 preferably includes selecting an optical fiber segment 18 having the same index of refraction (for both the core and the cladding) as the optical fiber 10 being adjusted and having a length determined by the formula:

[0028]
$$X = (L / TT) \cdot \Delta T$$

[0029] In the above equation, "X" represents the length of the optical fiber segment 18 to be added to the optical fiber 10 being adjusted. "L" represents the length of the optical fiber 10 being adjusted. "TT" represents the light transmission time of the optical fiber 10 being adjusted. " ΔT " represents the time difference between the light transmission time of the optical fiber 10 being adjusted and the optical fiber 10 having the longest transmission time. Thus, by adding an optical fiber segment 18 having a length determined by the above equation, skew in the optical fibers 10 is compensated. The ease in testing and reducing skew in optical fibers 10 using the method of the present invention allows optical fibers 10 to be grouped for a particular application prior to testing the optical fibers 10 for their respective transmission times. Subsequent to determining the respective transmission times

of the grouped optical fibers 10, optical material can be added as necessary. This greatly improves manufacturing efficiency for producing fiber optic cables 28 or grouped optical fibers 10.

[0030] Alternatively, when performing the method of the present invention, the amount of optical material can be adjusted using an optical fiber segment 18 having a different index of refraction from that of the optical fiber 10 being adjusted. It may be advantageous to add an optical fiber segment 18 having a different index of refraction when the use of a shorter optical fiber segment 18 is desired for a particular application. When an optical fiber segment 18 having a different index refraction is added to the optical fiber 10 being adjusted, it is preferred that an anti-reflective coating 26 be located between the optical fiber 10 being adjusted 10 and the optical fiber segment 18. The anti-reflective coating 26 reduces reflected light at the transition between the optical fiber 10 and an optical fiber segment 18 having a different index of refraction from the optical fiber 10.

[0031] It is preferred that the length of the optical fiber segment 10, which has a different index of refraction from the optical fiber 10 to which it will be added, be determined by the formula:

$$X = c \cdot n_2 \cdot \Delta T.$$

[0032] In the above equation, "X" represents the length of the optical fiber segment 18 to be added to the optical fiber 10 being adjusted. " n_2 " represents the group index of refraction of the optical fiber segment. " ΔT " represents the time difference between the light transmission time of the optical fiber 10 being adjusted and the optical fiber 10 having the longest transmission time. "c" represents the speed of light in a vacuum.

[0033] The method of the present invention may include selecting an optical fiber segment 18 for which the quantity L_2/TT_2 is known. When selecting an optical fiber

segment 18 for which the quantity L_2/TT_2 is known, the length of the optical fiber segment 18 is preferably determined by the formula:

[0034]
$$X = (L_2/TT_2) \cdot \Delta T.$$

[0035] In the above equation, "X" corresponds to the length of the optical fiber segment 18 to be added. L_2 is a length of the optical fiber (from which the optical fiber segment 18 is cut) when the optical fiber was measured to determine the quantity L_2/TT_2 . "TT₂" is the light transmission time of the optical fiber (from which the optical fiber segment 18 is cut) when the optical fiber 10 was measured to determine the quantity L_2/TT_2 . "ΔT" is the time difference between the light transmission time of the optical fiber 10 being adjusted and the optical fiber 10 having the longest light transmission time.

[0036] To reduce the overall light transmission time of at least one of the optical fiber 10 being used for a particular application, the method of the present invention may include the step of determining a length of optical fiber 10 to be removed from an optical fiber 10 having a relatively longer light transmission time as compared to the optical fiber 10 having the shortest light transmission time. It is preferred that the length of optical fiber 20 to be removed from the optical fiber 10 being adjusted is determined by the formula:

[0037]
$$X_R = (L / TT) \cdot \Delta T_2.$$

[0038] In the above equation, "X_R" is the length 20 of the optical fiber 10 to be removed from the one of the optical fibers 10. "L" is the length of the optical fiber 10 being adjusted. "TT" is the light transmission time of the optical fiber 10 being adjusted. "ΔT₂" is the time difference between the light transmission time of the optical fiber 10 being adjusted and the optical fiber 10 having the shortest light transmission time.

[0039] Referring to Fig. 5, the second preferred method of testing optical fibers 10 preferably tests the optical fibers 10 after the optical fibers 10 have been assembled into a fiber optic cable 28. This prevents the introduction of skew, due to the assembly of the fiber

optic cable 28, after the optical fibers 10 have been tested. The second preferred method of the present invention includes providing a fiber optic cable 28 including at least two optical fibers 10; transmitting a light at the first end of the fiber optic cable 28; measuring a light transmission time for each of the optical fibers 10; determining a difference in the light transmission times for the optical fibers 10 of the fiber optic cable 28; and determining whether the difference in the light transmission times is above a predetermined value. Contrary to the first preferred method of the present invention, the step of adjusting the amount of optical material in at least one of the optical fibers 10 is not necessarily part of the method of testing a fiber optic cable 28. When it is determined that the difference in light transmission times is below or equal to the predetermined value, the fiber optic cable 28 is ready for use in the desired application. If the difference in light transmission times indicates an unacceptable amount of skew, the amount of optical material can be adjusted in the same manner as that described above in connection with the first preferred method.

[0040] Referring to Fig. 4, the preferred method of testing optical fibers 10 according to the present invention is as follows. In step S1, at least two optical fibers 10 are provided. In step S2, light is transmitted through the optical fibers 10. In step S3, light transmission times are measured for each of the optical fibers 10. In step S4, the difference in light transmission times is compared to a predetermined maximum skew value to determine whether the difference between the fastest light transmission time and the slowest light transmission time is above a predetermined value. If the difference in light transmission times is not above the predetermined value for a particular application, then, the optical fibers 10 are ready for use. If the difference in light transmission times is above a predetermined value, then, in step S5, the amount of optical fiber material in at least one of the optical fibers 10 is adjusted to reduce the difference in light transmission times. As described in detail above, optical fiber segments can be removed from at least one of the

optical fibers 10 or additional optical fiber segments 18 may be added to one of the optical fibers 10 to reduce the difference in light transmission times.

[0041] Referring to Figs. 1-3 and 5, the preferred method of testing a fiber optic cable 28 according to the present invention is as follows. In step S10, a fiber optic cable 28 is provided that includes at least two optical fibers 10. In step S11, light is transmitted through the optical fibers 10. In step S12, a light transmission time for each of the optical fibers 10 is measured. In step S13, the difference in the light transmission times is compared to a predetermined value to determine whether the difference exceeds the predetermined maximum skew value for a particular application. If the difference in light transmission times is not above the predetermined value, the fiber optic cable 28 is ready for use. If the difference in light transmission times is above the predetermined value, then the fiber optic cable is probably not ready for the desired application.

[0042] It will be recognized by those skilled in the art, that changes may be made to the above-described embodiments of the present invention without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but is intended to cover all modifications which are within the spirit and scope of the invention as defined by the appended claims.